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Review Article

Digital soil map using the capability of new technology in Sugar Beet area, Nubariya, Egypt

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Land capability;
Land suitability

Abstract Due to the advances in the fields of remote sensing and GIS, a new paradigm, called digital soil mapping, is produced, where the emphasis is focused on soil attributes, assuming that these are continuously varying in space. Quantitative models have been developed within are used to describe, classify and study the spatial distribution patterns of soil as it occurs in the field.

In this paper the dynamic SWERI Data Collector system (SDC) was used to determine the location of the soil profiles in the field work using HP Global Position System (GPS). The DEM was created using the geostatistical analysis. The geomorphic mapping units were created based on the result of digital elevation model using the histogram of the DEM values map. The physiographic mapping units are created by combining the most surveyed geomorphic mapping units with the geologic map.

The variables of soil properties can be presented in values or classes, therefore two types of thematic maps could be identified. The first one used the values and the geostatistical analysis to create the soil variability value maps. The second type is descriptive variables such as soil classes and soil texture. The nearest point operation is a point interpolation which requires a point map as input and returns a raster map as output.

The integrated methodology of this study could be considered as a ready module for applying at different locations and represents a significant participatory management tool for soil survey in Egypt.

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Contents

1. Introduction

Soil survey has historically been a knowledge- and labor-intensive process, requiring a high degree of skill and even artistry, and of doubtful accuracy in the wrong hands. Traditional soil survey presents area-class maps of soil types, which represent the mapper's conceptual model of soil variability, backed up by field observations. Modern soil survey must present digital maps of interpreted soil properties (Lagacherie and McBratney, 2004).

In recent years thematic mapping has undergone a revolution as the result of advances in geographic information and remote sensing techniques. However, mapping of soil types and characteristics has not fully shared in this revolution, because of the complexity of soil geography and the high cost of its direct observation. Rossiter (2005) reviewed that the advances which are leading toward multiple-use soil information systems, included: (1) low-cost, wide-area data, especially elevations and spectral reflectance; (2) direct digital remote sensing of soil properties; (3) geostatistical interpolation and sampling design; (4) terrain modeling; (5) predictive soil mapping; (6) data integration; (7) pedotransfer functions and soil inference systems; (8) powerful desktop computing environments; (9) the Internet. McBratney et al. (2000) illustrated that there are basically two generic groups of techniques for soil survey in general: (1) the classical methods collectively referred here as the CLORPT methods, (2) the geostatistical methods. They added a third group as the hybrid methods. The hybrid methods are some combinations of techniques from the two generic groups to optimize prediction of soil properties.

(A) The CLORPT methods are based on the empirical-deterministic models that originated from Jenny's mathematical function of soil formation which expressed as: S = *f* (cl, o, r, p, t).

(B) Geostatistical methods are based on the theory of regionalized variables (Matheron, 1965), which allows us to consider spatial variability of a soil property as a realization of a random function that can be represented by a stochastic model. Geostatistics is now firmly established in soil science as a key tool for making the most of existing (generally sparse) data (Goovaerts, 1999; Webster and Oliver, 2001). Numerous studies have demonstrated that much local and even regional soil variability can be modeled as the result of random field (the somewhat disturbing theory behind geostatistical interpolation), and its use is almost universal for field-scale studies. It also provides a sound basis for designing optimal sampling plans (McBratney et al., 1981; Odeh et al., 1990; Kerry and Oliver, 2004; Stein and Ettema, 2003) based on the structure of spatial dependence.

(C) The hybrid techniques for soil survey are based on combinations of the geostatistical and multivariate or univariate CLORPT methods. Several methods have been designed to accommodate the trend. Universal kriging (Matheron, 1965) has been the commonly used method to accommodate the trend or the "changing drift", as it is sometimes known, in a soil variable. Cokriging is the multivariate extension of

kriging that allows the inclusion of more readily available and inexpensive attributes in the prediction process.

Terrain modeling a promising approach is the prediction of soil properties by digital terrain mapping (McKenzie et al., 2000; Ventura and Irvin, 2000; Bruin and Stein, 1998). It is a logical outgrowth of the strong relation between soil distribution and geomorphology (Gerard, 1992; Daniels and Hammer, 1992) and advances in automatic terrain classification from elevation models (Schmidt and Hewitt, 2004). The terrain modeling could be derived from DEM which is obtaining from topographic maps or SRTM (Shuttle Radar Missions) images.

These advances could be combined into the modern approach, and generally called predictive soil mapping (Scull et al., 2003). Most thematic maps are predictive, since not every location has been visited; but in this context it refers to a map made before field visits, using secondary data related to soil distribution to predict what soil type or characteristics should be found in each location; this can then be verified by efficient field sampling. A related approach is environmental correlation, where terrain units (Hengl and Rossiter, 2003) or soil properties (McKenzie and Ryan, 1999) are predicted by multiple regressions, using calibration samples.

Traditionally, soil surveys have been presented as area-class (''polygon'') maps with accompanying tabular information on soil properties in each class; these can easily be turned into GIS coverage with accompanying relational tables. Some surveys go one step further and provide soil survey interpretations for a range of anticipated uses, also as relational tables. This development has been particularly strong in the US Cooperative Soil Survey (Klingebiel, 1991; Olson et al., 1969; Olson, 1973), where close relations with a range of consumers of soil information (not just agricultural) were encouraged since the 1960's, finally resulting in the STATSGO (regional) and SSURGO (local) soil geographic databases. A similar level has been achieved in Canada and Australia.

Landscapes are considered to be complex systems that are hierarchically structured and spatially scale-dependent. Geopedology allows a systematic approach in geomorphic analysis for soil mapping that extrapolates the results obtained at sample areas up to similar units. Today there is great demand for accurate soil information over large areas from environmental modelers and land use planners (both urban and rural) as well as more traditional agricultural users of soil resource inventories.

The aim of this study is to use the capability of new technology to obtain the most efficient and accurate digital soils map, and then produce the land capability and suitability maps.

2. Materials and methods

2.1. Materials used

2.1.1. Location and general information of the studied area

The study area is located in the western part of El Nubariya region and cover part of Sugar Beet area. El Nasr irrigation canal is path through the study area from the south part. It is situated between 29° 37′ 02.58″ E and 29° 40′ 00.78″ E and between 30° 45′ 04.59″ N and 30° 52′ 37.33″ N, covering about 41,890 feddans (Fig. 1). In general the land elevation of the studied area ranges from 26 to 89 m above sea level. The slope of the area is ranged from 0.15% to 5.0%. The area is mostly flat and almost flat except for some parts in the south and north part of the studied area, which is gently sloping.

The area has a Mediterranean climate, characterized by rainy winter and prolonged hot and dry summer. The mean annual temperature is 20 °C. The maximum monthly temperature is 35.2° C in August and the minimum temperature is 7.9° C in January. Annual rainfall is low and ranged from 32.9 to 192 mm and most of the precipitation falls in winter

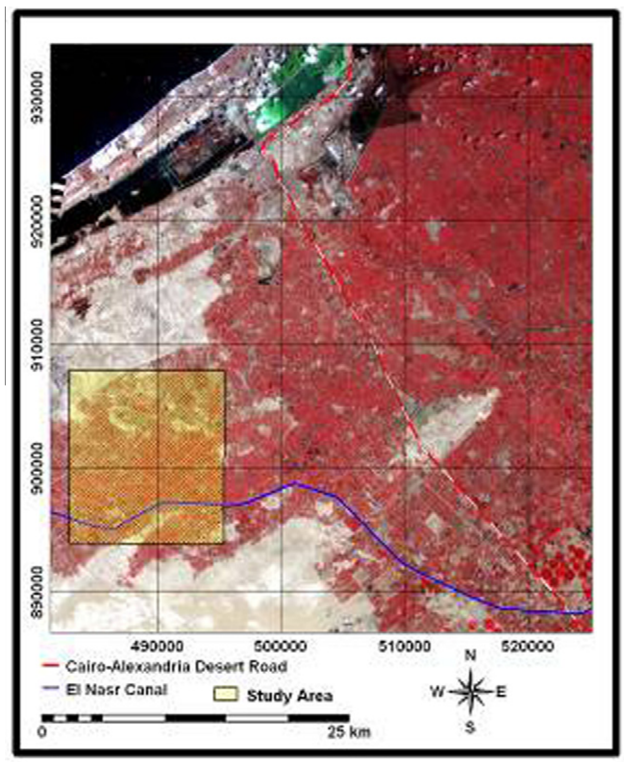

Figure 1 The location of the studied area.

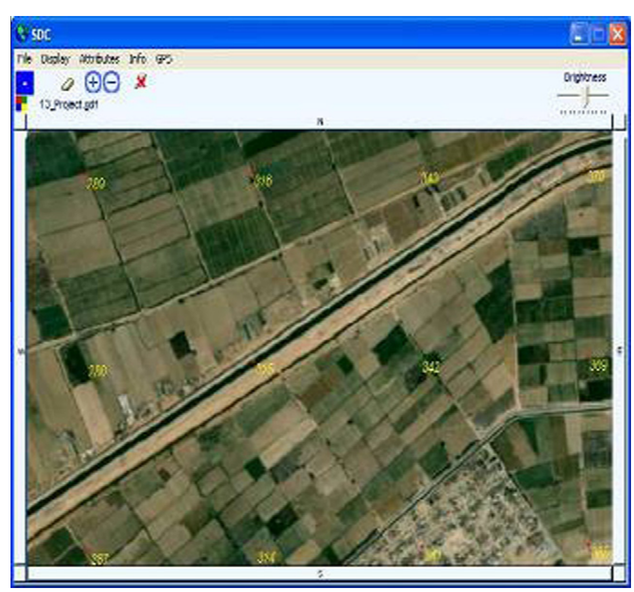

Figure 2 An example of using dynamic GPS for locating the soil profiles.

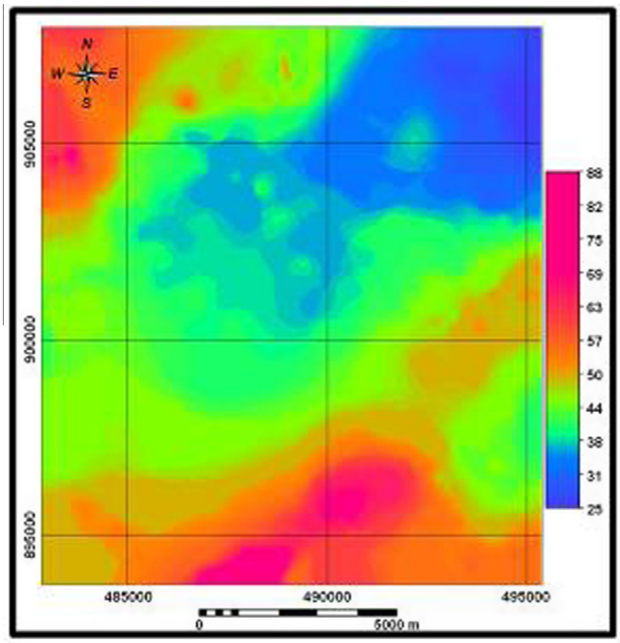

Figure 3 Raster contour values map.

(between October and March). The relative humidity ranges between 59% and 81%, within average of 69%. The maximum evapotranspiration is noticed in the warmer and dryer months, where it reaches up to 183 mm per month in June and July in Borg El Arab station. The lowest value was recorded in January with an evapotranspiration rate of 39 mm per month.

Soil moisture regime and soil temperature regimes are based on the meteorological data of Borg El Arab station. The soil moisture regime in study area is *Torric* or *Aridic* according to soil taxonomy definition (USDA, 2010). And the soil temperature regime in study area is *thermic*.

Recent and Halocene eolian sand and fluvial loams were most noticeable in the studied area. Late Pleistocene marine deposits were identified by the oolitic limestone distributed along the coast of the Mediterranean, west of Alexandria. These formations occur in chains extending parallel to the coast. Pleistocene limestone ridges are probably marine coastal beach ridges formed by successive high sea level. These formations constitute two groups. The upper group is limestone known as "Marmarican limestone" (the name borrowed from the region of northwestern Egypt). The second group is the Miocene strata, which is consisting of sandstone, limestone, and clays of about 400 m in thickness and containing characteristic fossil shells mainly of marine origin. The Recent and Halocene eolian sand and fluviatile loam were most noticeable in the southern part of the area. The study area is covered by undifferentiated quaternary deposits.

2.1.2. GIS software

Dynamic SWERI Data Collector system (SDC) was used to define and determine the location of the soil profiles in the field work using HP Global Position System (GPS). Fig. 2 shows an example of using Dynamic SWERI Data Collector system (SDC).Other SWERI Data convert system (SDC) was used to convert the shape file into GDF format. The ERDAS Imagine 9.1 was used for image enhancement and correction purposes, while Arc.GIS 9.2 and ILWIS 3.7 softwares were used for data gathering, data input, data storage, data manipulation, analysis, and data output capability by integrating conventional GIS.

2.1.3. Ancillary information

The following maps and reports were used in this study:

- The topographic sheet map of Borg El Arab, scale 1:50,000 were used to create the contour value point's map.
- Satellite images cover the study area (SPOT5).
- Existing soils map about the study area (Euroconsult – Pacer (1986); FAO group (1964a,b); Hamdi et al. (1982).
- The geological map of Egypt, scale 1:500,000 produced by the Egyptian General Petroleum Corporation (EGPC, 1988).
- The studied area boundary map was used as musk in all produced maps.

2.2. Methodology

The following methods used in the research include literature review, data collection, fieldwork, processing, analyzing, interpretation and extrapolation the available data of the studied area.

2.2.1. The map projection

The red built projection of the Egyptian Transverse Mercator (ETM) was applied to all the produced maps. The parameters of this projection were used as following, (1) Map projection: Transverse Mercator, (2) Datum: Old Egyptian 1907, (3) Ellipsoid: Halmert 1906, (4) Central Meridian: 31E, (5) Origin Latitude: 30 N, (6) False Easting: 615,000 m, and (7) False Northing: 810,000 m.

Table 1 The legend of physiographic mapping units.

Landscape	Relief	Lithology	Landform	Symbol	Area feddan	Area %
Ridges	Elongated hills	Marine deposits undifferentiated quaternary deposits	Summit	HI111	794	1.90
			Back slope	HI112	2158	5.15
			Foot slope	HI113	6707	16.01
			Toe slope	HI114	14837	35.42
	Mena valley	Marine deposits undifferentiated quaternary deposits	Inner	HI211	5389	12.87
			Outer	HI212	11612	27.72
	Hills	Marine deposits undifferentiated quaternary deposits	Knop	HI311	392	0.94
Total					42838	100.00

Table 2 The chemical analysis of some soil profiles of the studied area.

Profile No.	Depth in Cm	pH	EC (dS/m)	SP	Anions in mmohs				Catins in mmohs				SAR
					$CO_3^=$	HCO_3^-	Cl^-	$SO_4^=$	Ca^{++}	Mg^{++}	Na^+	K^+	
2	0–29	7.5	34.0	55	–	2.5	410.0	71.6	92.5	54.5	335.0	2.1	39.0
	29–70	7.9	29.0	50	–	2.0	290.0	81.4	51.5	22.0	298.0	1.9	49.0
	70–105	8.1	19.0	40	–	2.0	135.0	85.7	63.5	17.0	141.0	1.2	21.9
	105–130	7.6	12.0	42	–	2.0	100.0	30.9	18.5	22.3	91.0	1.1	20.1
4	0–20	7.6	2.0	55	–	3.0	6.0	11.6	10.3	5.0	5.1	0.2	1.8
	20–40	7.5	2.9	65	–	2.5	5.0	22.6	21.5	3.0	5.3	0.3	1.5
6	0–20	7.8	3.4	42	–	2.5	19.0	13.7	10.3	4.4	20.0	0.5	7.4
	20–60	7.9	2.7	65	–	2.0	17.0	9.1	7.2	3.6	17.1	0.2	7.4
	60–150	7.8	1.2	50	–	2.0	4.0	6.7	7.0	3.5	2.1	0.1	0.9
10	0–25	7.6	6.2	40	–	3.0	37.5	25.1	26.0	18.0	21.1	0.5	4.5
	25–70	7.6	8.2	40	–	2.5	52.0	31.6	19.6	11.5	54.1	0.9	13.7
	70–150	7.5	11.4	52	–	2.0	80.0	46.8	36.3	18.2	73.1	1.2	14.0
19	0–25	7.8	36.0	40	–	2.0	327.0	213.0	83.0	50.0	407.0	1.7	49.9
	25–60	7.8	35.0	45	–	2.0	327.5	113.2	80.2	40.3	320.5	1.7	41.3
	60–106	8.0	30.0	55	–	1.5	286.0	59.2	81.1	538.6	225.7	1.3	29.2
	106–150	7.9	10.4	30	–	1.5	73.0	37.6	25.1	15.3	70.5	1.2	15.7
27	0–35	7.7	2.3	40	–	3.0	12.0	8.8	8.2	3.9	11.5	0.2	4.7
	35–70	7.7	8.1	40	–	2.5	68.0	22.5	20.6	16.6	55.2	0.6	12.8
	70–100	7.7	3.2	40	–	2.5	17.0	13.5	14.3	5.3	13.0	0.4	4.2
	100–150	7.8	3.2	40	–	2.5	21.0	10.3	10.3	2.9	20.1	0.5	7.8
33	0–30	7.8	1.5	50	–	2.5	6.0	7.4	6.4	3.4	6.0	0.1	2.7
	30–100	7.9	2.1	60	–	2.0	12.5	6.2	8.8	0.5	10.1	0.3	4.4
	100–150	7.6	4.0	60	–	1.5	7.0	33.2	19.1	16.2	6.0	0.4	1.4
41	0–40	7.6	11.4	40	–	3.0	70.0	47.0	43.0	19.6	56.5	0.9	10.1
	40–110	7.8	4.4	40	–	2.5	21.5	22.5	17.4	7.1	21.5	0.5	6.1
	110–150	7.7	3.8	55	–	2.0	16.0	23.0	17.4	7.1	16.2	0.3	4.9
45	0–5	7.5	75.0	45	–	3.5	589.0	255.2	140.2	109.0	593.5	5.0	53.2
	5–20	7.6	80.0	38	–	3.5	524.0	379.6	200.0	164.1	540.5	2.5	40.1
	70–100	8.1	34.0	55	–	2.5	30.0	83.8	50.2	43.0	291.8	1.3	42.7
	100–150	7.9	4.0	40	–	1.5	8.1	32.5	20.4	14.2	7.2	0.3	1.7
48	0–20	7.8	4.3	60	–	1.0	18.0	26.6	14.8	12.0	17.9	0.9	4.9
	20–45	7.8	23.8	50	–	2.0	241.0	102.7	61.5	43.2	236.0	5.0	32.6
	45–80	8.1	6.7	50	–	2.0	15.5	54.3	30.5	25.0	14.2	2.1	2.7
	80–110	7.9	2.5	50	–	1.5	10.0	15.3	9.6	7.2	9.4	0.6	3.2
60	0–25	7.9	1.2	47	–	1.5	7.1	4.9	3.9	2.6	6.0	1.0	3.3
	25–70	7.7	1.5	47	–	1.0	4.0	11.0	6.9	5.0	3.8	0.3	1.5
	70–120	7.8	3.3	77	–	1.0	4.0	29.8	17.1	13.6	3.8	0.3	1.0
61	0–30	7.6	9.0	47	–	1.5	41.0	52.5	30.2	24.1	39.6	1.1	7.6
	30–80	7.8	3.2	47	–	1.0	5.0	28.3	17.3	11.8	4.9	0.3	1.3
	80–150	7.8	3.0	47	–	1.0	4.0	26.6	17.0	10.5	3.8	0.3	1.0
66	0–30	7.9	58.0	55	–	3.0	490.0	234.1	140.0	90.3	489.5	8.3	45.7
	30–60	7.8	27.5	40	–	2.0	207.0	108.5	61.0	41.2	210.3	5.0	29.4
	60–100	7.6	2.0	48	–	1.0	9.0	10.2	6.9	4.2	8.9	0.3	3.8
69	0–30	7.7	10.5	60	–	3.5	52.0	57.5	63.6	24.6	24.6	0.2	3.7
	30–45	7.9	4.8	60	–	2.0	10.0	38.4	30.5	8.2	11.5	0.2	2.6
	45–100	7.8	4.3	40	–	1.0	10.0	34.0	30.4	5.4	9.1	0.1	2.2
70	0–30	8.0	40.0	50	–	3.5	388.0	116.5	51.3	56.5	398.0	2.2	54.2
	30–60	8.0	12.0	40	–	2.0	105.0	27.2	30.8	17.2	85.0	1.2	17.3
	60–90	8.0	52.0	40	–	1.5	510.0	109.5	35.9	71.9	512.0	1.2	69.8
71	0–30	7.8	7.1	50	–	2.5	20.0	51.7	19.4	12.3	42.1	0.4	10.6
	30–60	7.9	25.0	47.5	–	2.0	235.0	119.3	110.8	22.9	222.2	0.4	27.2
	60–150	7.9	5.2	57.5	–	2.0	14.0	38.0	19.5	17.1	17.2	0.3	4.0

2.2.2. Create the physiographic mapping units

The contour lines including the ground control points were delineated from the topographic maps (scale 1:50,000) in a grid system with spacing of 250 m. The Digital Elevation Model (DEM) was created using the geostatistical analysis. The estimated or predicted values are thus a linear combination of the input values. Geostatistical analysis was carried out at a two step procedure: (a) the calculation of the experimental semi-variogram and fitting a model; and (b) interpolation through Ordinary Kriging, which uses the semi-variogram parameters (Stein, 1998). The geomorphic mapping units were created based on the result of the histogram of the DEM value map. The geopedological soil map approach (Zinck, 1998) was followed to create the physiographic mapping units by combining the geomorphic mapping units with the geological map. The physiographic mapping units are created by

Table 3 The physical analysis of some soil profiles of the studied area.

Profile No	Depth in cm	Piratical size distribution %				Texture	Gypsum	OM	$CaCO_3$
		Coarse sand	Fine sand	Silt	Clay				
2	0–29	25	27	20	28	Sand clay loam	25	0.27	18.8
	29–70	23	28	20	29	Sand clay loam	12	0.26	16.7
	70–105	21	25	24	30	Sand clay loam	11.2	0.26	23.0
	105–130	27	23	24	26	Sand clay loam	10.5	0.23	23.0
4	0–20	10	18	40	32	Clay loam	6	0.83	20.9
	20–40	11	15	39	35	Clay loam	4	0.46	20.9
6	0–20	25	24	23	28	Sand clay loam	10.3	0.53	16.7
	20–60	10	12	35	43	Clay	5	0.33	18.8
	60–150	18	17	25	40	Clay	3.4	0.27	20.9
10	0–25	20	26	25	29	Sand clay loam	22	0.48	25.1
	25–70	25	21	21	33	Sand clay loam	16	0.31	27.3
	70–150	19	13	33	35	Clay loam	12.3	0.27	29.3
19	0–25	24	25	22	29	Sand clay loam	19	0.25	25.1
	25–60	24	25	26	25	Sand clay loam	18	0.23	27.2
	60–106	16	20	33	31	Clay loam	15.6	0.25	27.2
	106–150	17	19	34	30	Clay loam	15.4	0.25	29.6
27	0–35	24	26	20	30	Sand clay loam	26	0.69	20.9
	35–70	21	31	19	29	Sand clay loam	22	0.68	16.7
	70–100	25	29	18	28	Sand clay loam	19.2	0.67	16.7
	100–150	41	42	8	9	Sandy loam	12.3	0.34	25.1
33	0–30	15	17	33	35	Clay loam	9.6	0.82	27.2
	30–100	15	16	35	34	Clay loam	5.6	0.81	16.7
	100–150	11	15	40	34	Clay loam	5.3	0.63	23.0
41	0–40	24	25	20	31	Sand clay loam	2.3	0.69	16.7
	40–110	24	25	21	30	Sand clay loam	1.5	0.67	20.9
	110–150	12	14	40	34	Clay loam	1.5	0.69	25.1
45	0–5	20	24	38	18	Loam	12	0.32	27.2
	5–20	23	27	21	29	Sand clay loam	6.9	0.3	20.9
	70–100	12	13	40	35	Clay loam	5.6	0.41	25.1
	100–150	23	27	21	29	Sand clay loam	5.5	0.32	29.3
48	0–20	10	14	30	46	Clay	9.2	0.58	16.7
	20–45	13	17	35	35	Clay loam	3.6	0.56	20.9
	45–80	13	17	34	36	Clay loam	2.6	0.54	25.1
	80–110	13	15	38	34	Clay loam	2.5	0.54	16.7
60	0–25	22	26	23	29	Sand clay loam	1.2	0.69	27.2
	25–70	25	26	22	27	Sand clay loam	1.1	0.64	18.8
	70–120	23	27	24	26	Sand clay loam	1.02	0.62	20.9
61	0–30	24	28	15	33	Sand clay loam	1.2	0.74	12.5
	30–80	27	28	15	30	Sand clay loam	0.6	0.70	18.8
	80–150	24	28	16	32	Sand clay loam	0.5	0.69	20.9
66	0–30	16	20	30	34	Clay loam	3.6	0.69	23.0
	30–60	25	26	20	29	Sand clay loam	2.1	0.57	23.0
	60–100	24	27	19	30	Sand clay loam	2.1	0.56	31.4
69	0–30	21	27	8	44	Clay	8.6	0.62	16.7
	30–45	25	26	20	29	Sand clay loam	3.2	0.61	16.7
	45–100	23	27	20	30	Sand clay loam	3.1	0.59	16.7
70	0–30	12	13	40	35	Clay loam	1.02	0.53	14.6
	30–60	12	13	41	34	Clay loam	0.5	0.47	14.6
	60–90	24	25	22	29	Sand clay loam	0.5	0.46	16.7
71	0–30	12	13	40	35	Clay loam	13.6	0.69	16.7
	30–60	26	28	20	26	Sand clay loam	10.5	0.63	18.8
	60–150	24	28	21	27	Sand clay loam	10.5	0.61	18.8

combining the geomorphic mapping units with the geologic map. Finley the physiographic soil map is obtained by integration between the physiographic mapping units with the soil classification map.

2.2.3. Contour point's map

The point editor in ARC-GIS 9.2 was used to create a contour map, by digitizing the contour values, which intercept with the grid system at intervals of 250 m. The altitude of control points, located on the topographic maps, was digitized with the contour point's map.

2.2.4. Spatial correlation and empirical semi-variogram

The point statistics determined the nature of the contour altitude values map, to elaborate the geostatistical parameters for Kriging interpolation method. The Kriging process models the discrete values of the experimental semi-variogram, which gives the expected value for any desired distance. The dependent output table was defined and calculated. According to the spatial correlation, the semi-variogram models were developed.

2.2.5. Field work

The field work was done in the October 2010 by digging seventy-two soil profiles to elaborate and study the soil characteristics to classify the pedons to Great group level (USDA, 2010), morphological sheets were filled according to the guideline (USDA, 2006), then soil samples were collected for lab analysis, from the pedons that represent different soil types and described according to the difference between layers. The location of soil profiles was selected according to the physiographic mapping units and the homogeny level of the studied soil. Seventy-two soil profiles were morphologically described and soil samples of the profiles were collected according to the differences between the layers. Detailed macro-morphological description sheets were recorded following the guidelines edited by USDA (1993).

2.2.6. Laboratory work

Soil samples were air dried, gently crushed, and then sieved through a 2-mm sieve. Fraction below 2 mm were subjected to soil chemical and physical analyses. Soil color for both moist and dry samples using Munsell color charts, USDA (1975) was examined. Particle size distribution was analyzed by Hydrometer method (Richards, 1954). Total calcium carbonate was determined by Collin's Calcimeter (Nelson, 1982). The electrical conductivity of the saturated soil paste extract was carried out according to Rhoades (1982). Soil reaction (pH) was determined in (1:2.5) soil: water suspension using Beckman pH meter, Mclean (1982). The water extract components were determined in the soil extract, as follows:

- The carbonates and bicarbonates by titration using Phenolphthalein and Bromocresol green as indicators, Jackson (1967).
- The chlorides using Mohr's method, Jackson (1967).
- Calcium and magnesium were determined by versenate method using ammonium perpiorate as an indicator for calcium and magnesium, and erochrom black T as indicator Jackson (1967).
- Sodium and potassium were determined photometrically using perking Elmer flame photometer, Jackson (1967).
- The sulfates were calculated by subtracting the summation of the soluble anions from total soluble cations.

2.2.7. Produce thematic maps

Two types of thematic maps can be identified. The first one deals with the values and the geostatistical analysis to create the soil variability value maps. Kriging can be seen as a point interpolation which requires a point map as input and returns a raster map with estimations and optionally an error map. The estimations are weighted average input point values, similar to the Moving Average operation. The weight factors in Kriging are determined by using a user-specified semi-variogram model (based on the output of the spatial correlation operation), the distribution of input points, and are calculated in such a way that they minimize the estimation error in each output pixel. The estimated or predicted values are thus a linear combination of the input values and have a minimum estimation error. Two methods are available: Simple Kriging and Ordinary Kriging. The optional error map contains the standard errors of the estimates (ILWIS 3.7, 2010).

The second type is descriptive variables such as soil classes and soil texture. The nearest point operation is a point interpolation which requires a point map as input and returns a raster map as output. Each pixel in the output map is assigned the class name, identifier, or value of the nearest point, according to Euclidean distance. This method is also called Nearest Neighbor or Thiessen. The points in the input point map for the nearest point operation do not need to be values necessarily; point maps (or attribute columns) with a class, ID or bool domain are also accepted. The soil texture and soil taxonomy classification information are used in this part to produce the texture and taxonomic maps of the study area (ILWIS 3.7, 2010).

2.2.8. Physiographic and soil map

The capability of GIS was used to combine the physiographic mapping units with the soil classification map to produce the physiographic and soil map. The physical and chemical soil properties were incorporated with physiographic soil map to obtain the land capability map.

2.2.9. Land capability map

The crossing operation was used to obtain the land quality map (Erian, 2000; Erian et al., 2000; FAO, 1985) of the studied area using the selected soil properties (effective soil depth, soil salinity, soil alkalinity, Gypsum % and $CaCO_3$%).

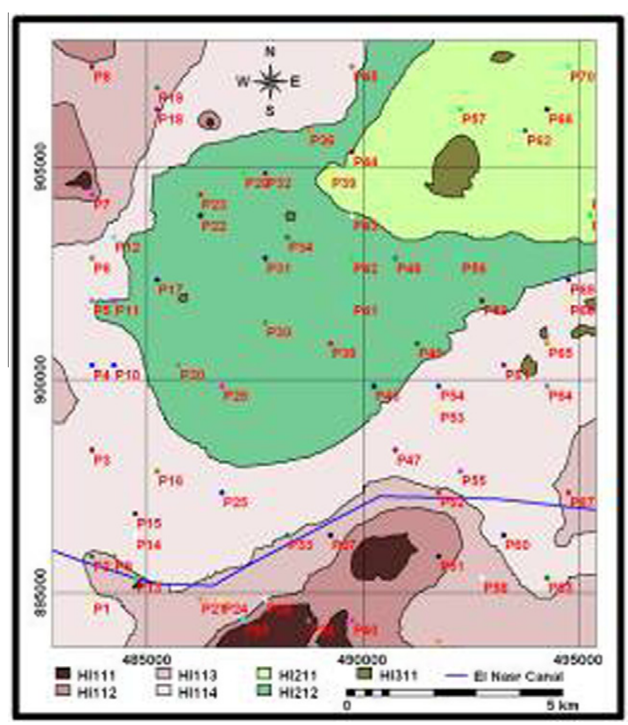

Figure 4 Physiographic mapping units with profiles location of the studied area.

3. Results and discussion

3.1. Digital elevation model

The total numbers of contour point's are 2688, covering about 41,890 feddans of the studied area. The values of the contour point's map ranged between 25 to 88 m a.s.l. with an average of 48.04 m a.s.l. The results of the spatial correlation and empirical semi-variogram show that the lag distance is 250 m and the number of lags is 77 lags. The number of pairs is ranged from 3814 pairs to 89191 pairs with an average of 46900 pairs. The limited distance is 14 km. The Kriging parameters of seven models and their goodness of fitting were analyzed using the capability of ILWIS 3.7. The results show that the parameters of Spherical model were most fitted one to the experimental semi-variogram (R^2 = 0.92).

3.2. Creation of physiographic mapping units from DEM

The parameters of the best fitting model of Spherical model were used to calculate the DEM values map. The raster contour values map of applying Kriging is shown in Fig. 3. The values of the raster map for the studied area ranged from 26 to 88 m a.s.l. The mean values were 47.95 m a.s.l.

The contour value and the kriging error maps were compiled, and then the fill sink operation was applied. The DEM value map was used to delineate the boundaries of the geomorphic mapping units after using the histograms operation. The Geomorphic mapping units were combined with the geological map and the Hill shaded map using the capability of GIS software to create the physiographic mapping units (Fig. 4 and Table 1).

One landscape units were delineated, (Ridges). The ridges are subdivided to three main relief types (Elongated Hills, Hills, and Mena valley). Each relief type was classified into seven landform units according to Zinck (1998). According to the geological map, the extensive ridge, rementated ridge, and mena valley were derived from undifferentiated quaternary deposits.

3.3. Soil characteristic

Soil samples were air dried, gently crushed, and then sieved through a 2-mm sieve. Fractions below 2 mm were subjected to soil analyses. The Chemical and physical properties of the soil samples were determined (Tables 2 and 3). The results show the dominant texture of sand clay loam, sandy loam, loam and sandy clay loam. The soils of this area have very

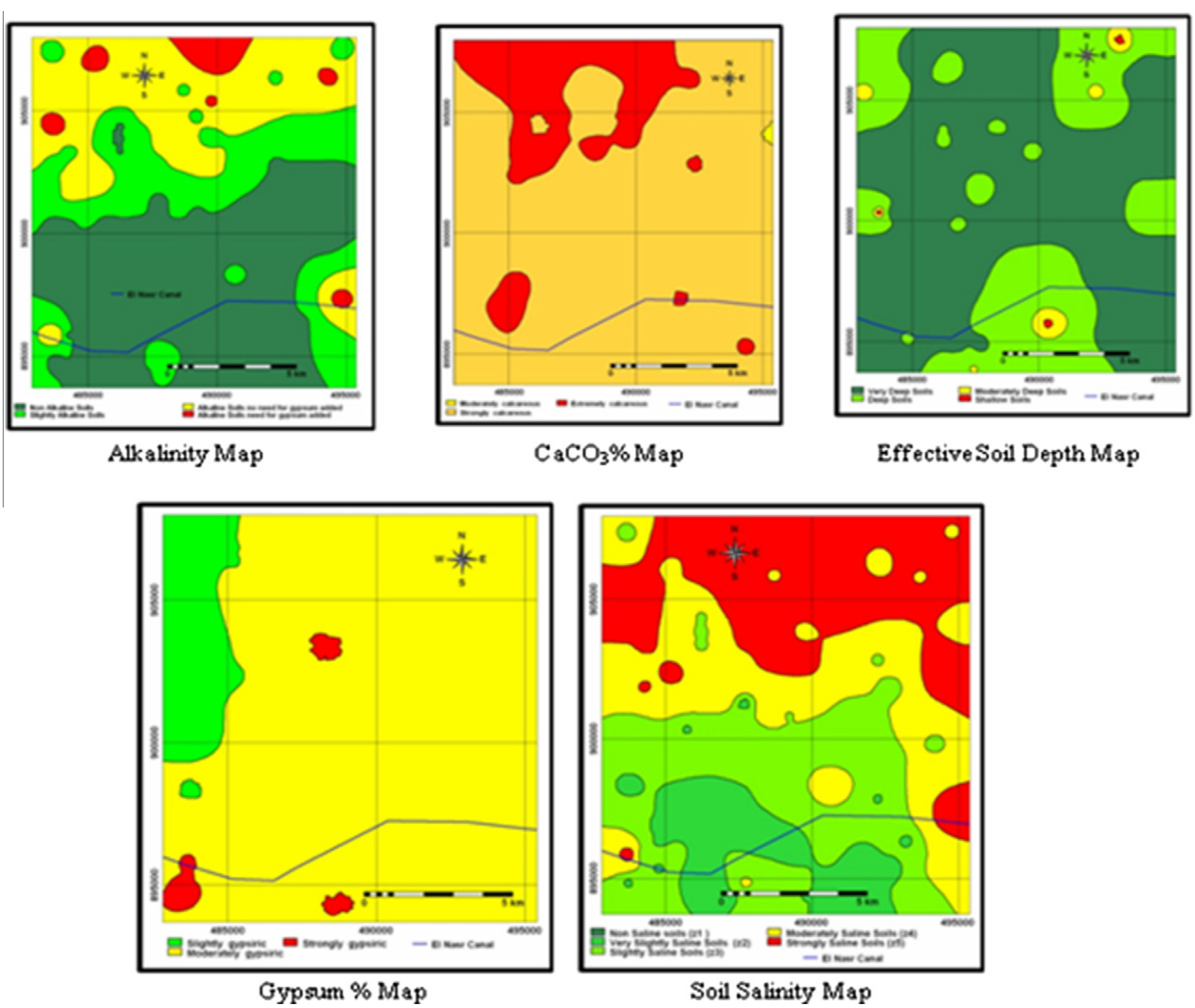

Figure 5 The selected soil properties maps of the studied area.

Table 4 The areas and its % for the selected soil properties of the study area.

Soil properties	Classes	Area in Feddan	Area %
Soil salinity	Very slightly saline soils (z2)	5196	12.40
	Slightly saline soils (z3)	12539	29.93
	Moderately saline soils (z4)	11623	27.75
	Strongly saline soils (z5)	12532	29.92
	Total	41890	100.00
Soil alkalinity	Non alkaline soils	18776	44.82
	Slightly alkaline soils	10198	24.34
	Alkaline soils no need for gypsum added	11548	27.57
	Alkaline soils need for gypsum added	1367	3.26
	Total	41890	100.00
CaCO3%	Moderately calcareous	64	0.15
	Strongly calcareous	34446	82.23
	Extremely calcareous	7380	17.62
	Total	41890	100.00
Gypsum %	Slightly gypsiric	4513	10.77
	Moderately gypsiric	36689	87.59
	Strongly gypsiric	687	1.64
	Total	41890	100.00
Effective soil depth	Shallow soils	47	0.11
	Moderately deep soils	668	1.60
	Deep soils	12497	29.83
	Very deep soils	28678	68.46
	Total	41890	100.00

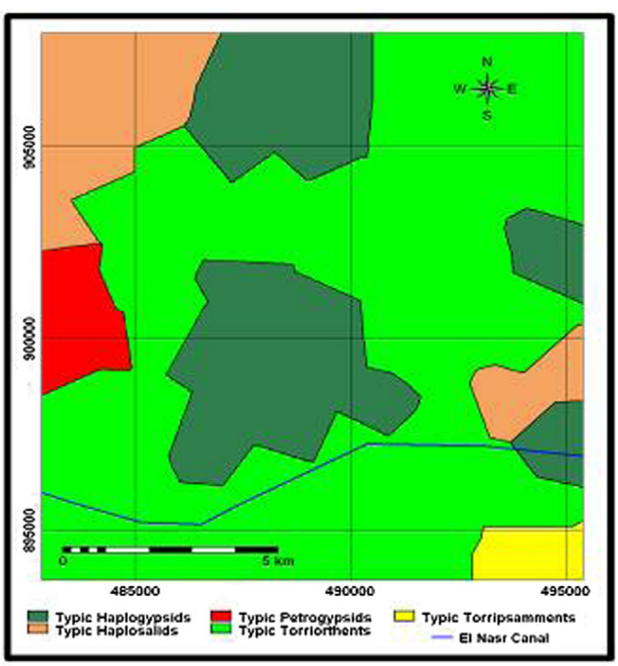

Figure 6 The soil classification map of the study area.

deep to shallow deep effective soil depth and ranged from 45 cm to 150 cm with an average of 120.6 cm. The EC values ranged from 0.13 to 76.2 dS/m with an average of 2.37 dS/m, therefore, most of this soil is non- saline soils to moderately saline soils and small area is classified as strongly saline soils. The dominant salt is sodium chloride. The pH values ranged from 7.4 to 9.02 with an average of 8.34. The SAR ratio ranged from 1.0 to 65.52 with an average of 3.66. Most of these soils are non alkaline to alkaline soils and there is no need for added gypsum and small part alkaline soils there is need for added gypsum (3.26% from the total study area). The total content of calcium carbonate percentage ranged from 14.05% up to 65.17% with an average of 21.5%. These soils are strongly to extremely calcareous soils. The gypsum content percentage is low and ranged from 0.14% to 25.3% with an average of 2.25%. It is classified as slightly to moderately gypsiric soils. Only small area is classified as strongly gypsiric soils. The organic matter percentage is low and ranged from 0.14% to 2.2% with an average of 0.86%. The ground water depth ranged from 100 cm up to more than 150 cm, therefore, these soils are classified as very deep to deep ground water.

Table 5 The soil classification classes of the study area.

Taxonomy units	Area in feddan	Area %
Typic Haplogypsids	14277	34.08
Typic Haplosalids	1124	2.68
Typic Petrogypsids	324	0.77
Typic Torriorthents	25939	61.92
Typic Torripsamments	225	0.54
Total	41890	100.00

3.4. Produce thematic maps

3.4.1. Thematic value maps

From the geostatistical analyses, all the variables of weighted average layer of 60 cm (effective soil depth, soil salinity, soil

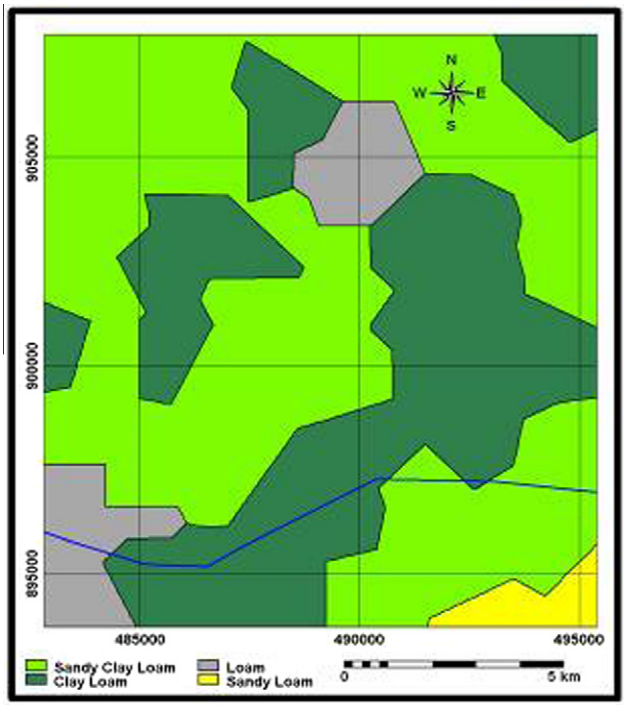

Figure 7 The soil texture map of the study area.

Table 6 The soil texture classes of the study area.

Soil texture classes	Area in Feddan	Area %
Clay loam	15315	36.56
Loam	3198	7.63
Sandy clay loam	22523	53.77
Sandy loam	855	2.04
Total	41890	100.00

Table 7 The results of crossing operation to create physiographic and soil map.

Physiographic and soils	Area in Feddan	Area % per mapping unit	Kinds of map units
HI111-Typic Torriorthents	755	95.60	Consociation
HI111_Typic Haplosalids	35	4.40	
Total of mapping unit	790	100.00	
HI112-Typic Haplosalids	578	26.75	Consociation
HI112-Typic Torriorthent	1581	73.25	
Total of mapping unit	2158	100.00	
HI113-Typic Haplogypsids	150	2.24	Complexes and associations
HI113-Typic Haplosalids	2453	36.64	
HI113-Typic Petrogypsids	134	2.00	
HI113-Typic Torriorthents	3475	51.91	
HI113-Typic Torripsamments	482	7.20	
Total of mapping unit	6694	100.00	
HI114-Typic Haplogypsids	2835	19.20	Complexes and associations
HI114-Typic Haplosalids	2988	20.23	
HI114-Typic Petrogypsids	1633	11.06	
HI114-Typic Torriorthents	7312	49.51	
Total of mapping unit	14769	100.00	
HI211-Typic Haplogypsids	955	17.61	Complexes and associations
HI211-Typic Haplosalids	1059	19.54	
HI211-Typic Torriorthjents	2761	50.90	
HI211-Typic Torripsamments	648	11.95	
Total of mapping unit	5423	100.00	
HI212-Typic Haplogypsids	2859	24.48	Complexes and associations
HI212-Typic Haplosalids	307	2.63	
HI212-Typic Torriorthents	7082	60.64	
HI212-Typic Torripsamments	1431	12.26	
Total of mapping unit	11679	100.00	
HI311-Typic Haplogypsids	44	11.60	Complexes and associations
HI311-Typic Haplosalids	11	2.85	
HI311-Typic Torriorthents	268	71.21	
HI311-Typic Torripsamments	54	14.34	
Total of mapping unit	376	100.00	
Total of study area	41890		

alkalinity, and $CaCO_3$%) are highly spatial dependency. The Gypsum % is not spatial dependency. Therefore, the Kriging method is used to interpolate the variables of effective soil depth, soil salinity, soil alkalinity, and $CaCO_3$% to produce these variable maps. The moving average interpolation method is used to produce the Gypsum % map of the study area.

Fig. 5 and Table 4 show the different classes of the effective soil depth, soil salinity, soil alkalinity, Gypsum % and $CaCO_3$% maps and its area percentage from the total study area.

3.4.2. Thematic descriptive maps

The soil texture and soil taxonomy classification information are used to produce the texture and taxonomic maps of the study area. The operation of nearest point interpolation method was used to create the soil texture map of the study area. The operation of moving weighted average interpolation method was used to create the soil taxonomy map of the study area. Fig. 6 and Table 5 show the soil classification map and its area % from the total study area. Fig. 7 and Table 6 show the soil texture classes' map and its area % from the total study area.

3.5. Physiographic and soil map

The crossing operation was used to create the land quality map and the final physiographic and soil map. Table 7 and Fig. 8 show the physiographic and soil map of the study area.

3.6. Land capability map

Current land quality classes were obtained from the field data and the potential land quality was created after butting assumption using leaching process to reduce the soil salinity one class. Fig. 9 and Table 8 show the current land quality of the study area. Fig. 10 and Table 9 show the potential land quality of the study area.

4. Conclusion

The integrated methodology of this study could be considered as a ready module for applying at different locations and represents a significant participatory management tool for soil

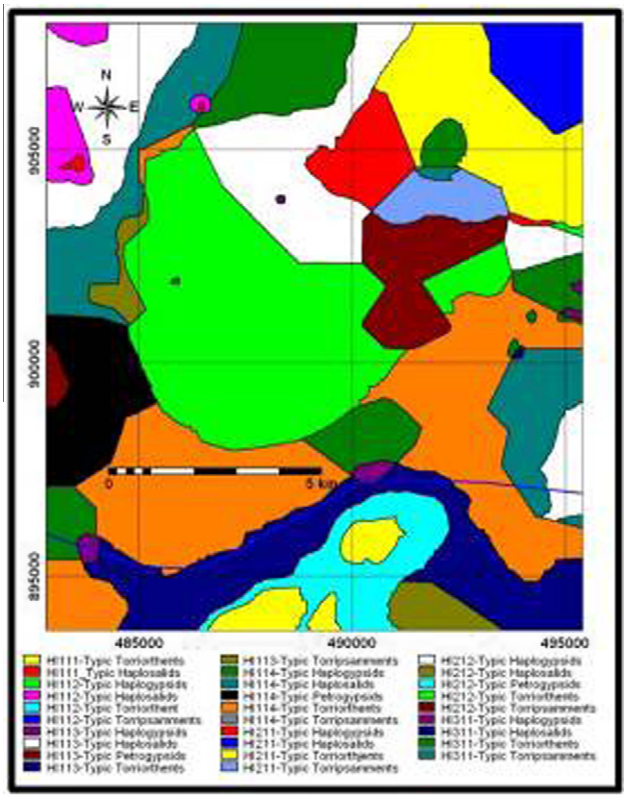

Figure 8 The soils and physiographic mapping units of the studied area.

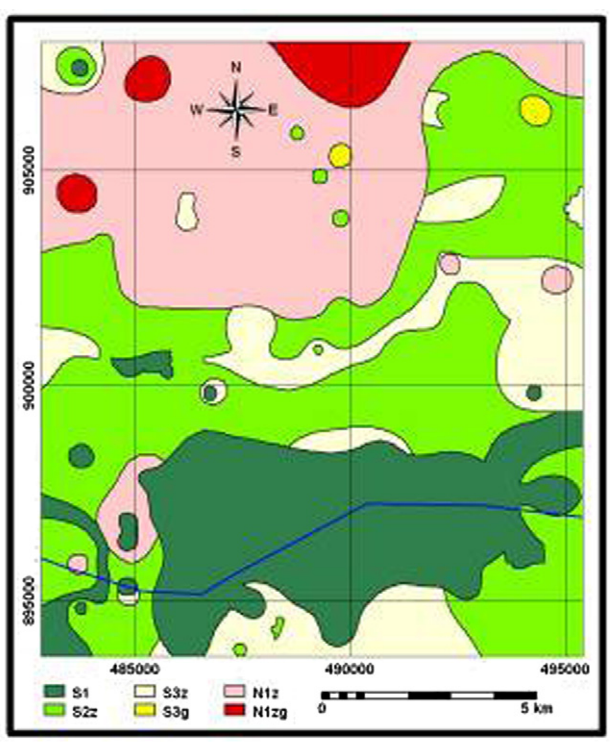

Figure 9 Current land quality map of the studied area.

survey in Egypt. Soil survey technology related fields, such as soil informatics and digital processing are not yet given high priority in many countries. Field surveyors; however, seem to

Table 8 Current land quality classes of the study area.

Land quality classes	Area in feddan	Area %
S1 no limitations	8997	21.48
S2z slight limitations due to soil salinity	14449	34.49
S3z moderate limitations due to soil salinity	5697	13.60
S3g moderate limitations due to soil alkalinity	148	0.35
N1z marginal limitations due to soil salinity	11472	27.39
N1zg marginal limitations due to soil salinity and alkalinity	1127	2.69
Total	41890	100.00

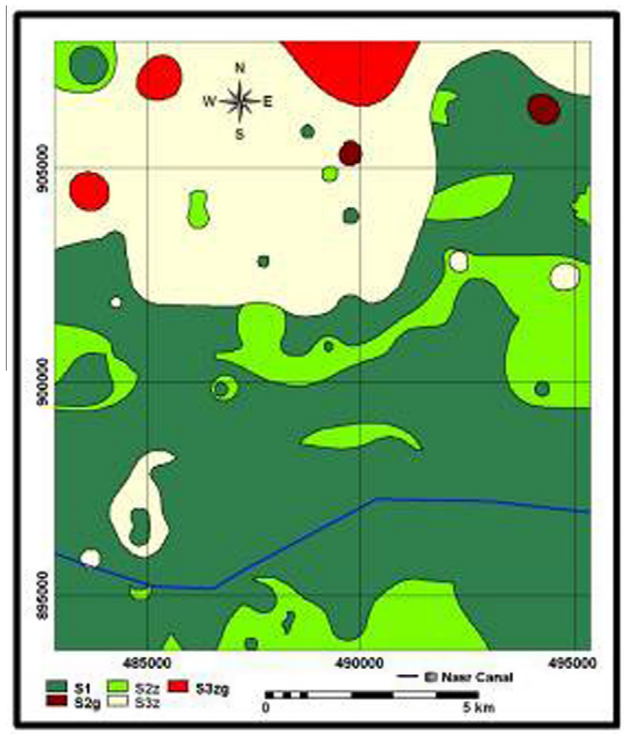

Figure 10 Potential land quality map of the studied area.

Table 9 Potential land quality classes of the study area.

Land quality classes	Area in feddan	Area %
S1 no limitations	23263	55.53
S2g slight limitations due to soil alkalinity	149	0.36
S2z slight limitations due to soil salinity	5883	14.04
S3z moderate limitations due to soil salinity	11468	27.38
S3zg moderate limitations due to soil salinity and alkalinity	1127	2.69
Total	41890	100.00

The results show that the current land suitability for agriculture is about 69% of the studied areas that are classified from S1 up to S3 and the main limitations are due to soil salinity (44% of the studied area). The potential land suitability for agriculture after reducing the soil salinity is 100% of the studied areas that are classified from S1 up to S3 and the main limitations are due to soil salinity (30% of the studied area).

be more sensitive than survey managers to the implementation of these new techniques, especially in relation to soil mapping, legend construction using accurate, standardized geomorphologic terms and soil data handling (soil database). It is needed to understand how to integrate the quantitative methods with the qualitative method to produce the most purveyed soil boundary and efficient and sufficient soil map.

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